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MONSANTO RESEARCH CORPORATION

A SUBSIDIARY OF MONSANTO COMPANY

MOUND LABORATORY

MIAMISBURG, OHIO

OPERATED FOR

UNITED STATES ATOMIC ENERGY COMMISSION

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ABSTRACT

Electron beam welding techniques were developed for joining 0.080-inch, high-purity annealed tantalum sheet. Maximum joint strength with minimum heat input was desired. In preliminary studies it was determined (1) that weld penetration of the tantalum could be controlled within ± 0.003 inch; and (2) that tensile and yield strength were slightly higher for the weld metal than for the parent material, although the elongation decreased from 40.5 to 23.5% due to recrystallization of the metal. Weld specimens were prepared with 0.020 x 0.020-inch step joints (which were easier to machine than the initially tested 0.010 x 0.010-inch step joints). The joint efficiency was 92% with only 75% penetration. Additionally, the low power requirements (1320 joules per inch) gave a maximum temperature of 300°C at the metal surface opposite the weld.

End

ELECTRON BEAM WELDING OF ANNEALED TANTALUM SHEET

Introduction

Electron beam welding techniques were developed for joining 0.080-inch thick, high-purity annealed tantalum sheet to obtain maximum joint strength with minimum heat input. Electron beam welding is superior to tungsten inert gas welding because the penetration can be more precisely controlled, and the heat input is less, thus reducing grain growth. Because of the reduced grain growth, these welds have excellent strength and corrosion resistance.

The studies were conducted in the following sequence:

1. Electron beam welding parameters were established for various depths of penetration.
2. Mechanical properties of the parent material were determined.
3. Mechanical properties of the weld metal were determined.
4. Specimens with 0.010 x 0.010-inch step joint welds were evaluated.
5. Specimens with 0.020 x 0.020-inch step joint welds were evaluated.

Apparatus

A Hamilton Standard Model Number W1-6 high power density electron beam welder with a maximum accelerating potential of 150 kilovolts and a maximum beam current of 20 milliamperes was used in the study. All welds were made in a vacuum of less than 10^{-4} torr.

An Instron tensile testing instrument was used to determine the mechanical properties and joint efficiencies of the tantalum parent material and weld specimens.

Penetration Studies

The welding studies were begun by passing the electron beam across a sheet of 0.080-inch annealed tantalum sheet as shown in Figures 1 and 2. This bead-on-plate welding was used to establish the electron beam welding parameters without the additional variable of joint fitting. The passes were made using a variety of welder settings (kilovolts, milliamperes, and traversing speed – speed at which weld is being made) to obtain a setting that would give the desired penetration of 0.070 inch (Table 1). It was determined that penetration could be controlled to $\pm$ 0.003 inch either on a bead-on-plate or good fitting joint weld.

Void areas appeared at the roots of the welds on all of the bead-on-plate welds (Figures 3 and 4). The voids are not detrimental to butt or step joint welds since such voids would be a part of the interface below the weld area. These voids are common in electron beam welding and have been noted in several metals; they may be due to occluded gases present in the metal and/or to vaporization of the metal (or impurities) during the welding process.

Mechanical Properties of Annealed Tantalum Sheet

Microhardness tests were conducted on the parent tantalum. The average Vickers' microhardness was 105 kg/mm^2 which compares well with the literature values of 108 kg/mm^2 for annealed tantalum sheet. This comparison verified that the initial material used in the studies was fully annealed. The starting material was also analyzed for impurity content; the results are shown in Table 2.

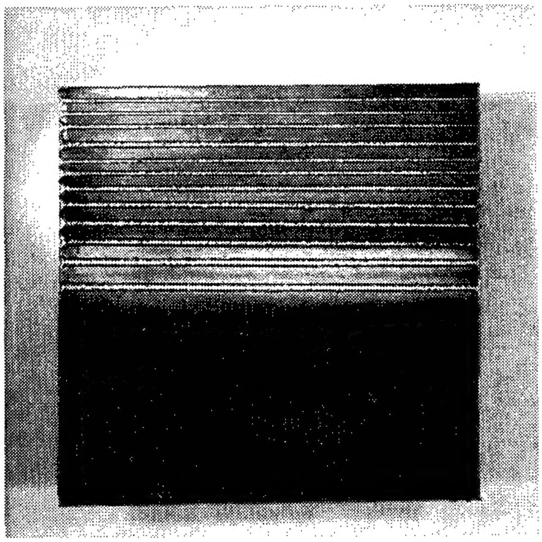

Figure 1. *Typical bead-on-plate welds (1X); the welds are made from top to bottom.*

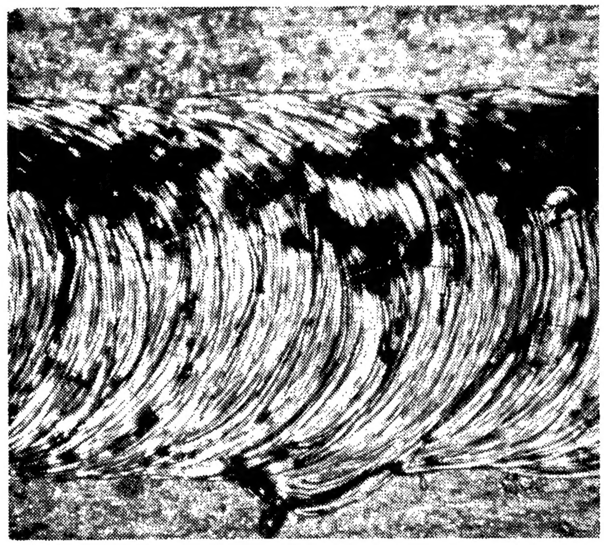

Figure 2. *The bottom weld of Figure 1 (52X); note the grain boundaries on the weld bead.*

Table 1

Penetration of Bead on 0.080-Inch Thick Tantalum Plate[a]

Weld Pass Number[b]	Accelerating Potential (kv)	Beam Current (ma)	Penetration (in.)	Total Energy Input (joules/in.)
1	100	4.8	0.030	800
2	115	4.0	0.034	920
3	115	5.0	0.040	1150
4	115	6.0	0.052	1380
5	120	4.0	0.040	960
6	120	5.0	0.048	1200
7	120	6.0	0.058	1440
8	120	7.0	0.068	1680
9	125	6.0	0.068	1500
10	130	6.0	0.068	1560
11	125	7.0	0.080	1750
12	125	6.5	0.072	1625

[a]Welding speed – 30 in./min.

[b]These numbers correspond to the 12 welds in Figure 1. Weld Number 1 is at the top.

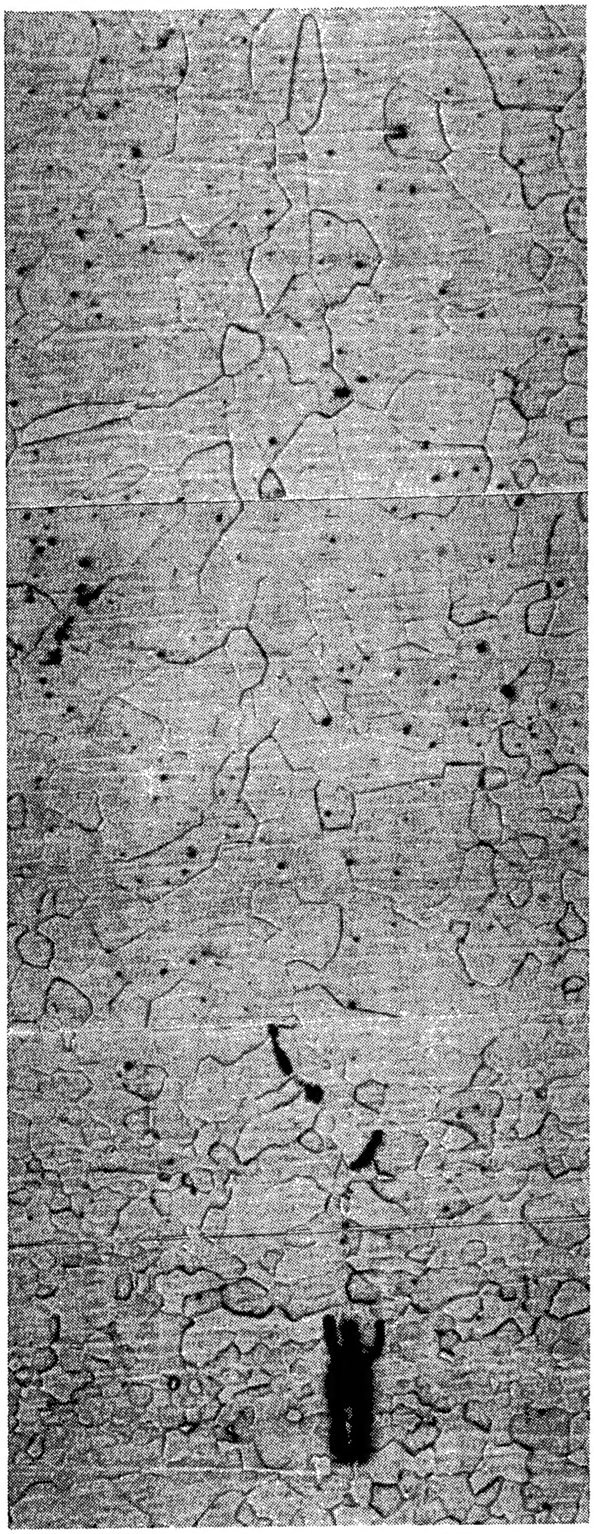

Figure 3. *Photomicrograph showing voids (dark spots) and grain structure in the weld area (100X).*

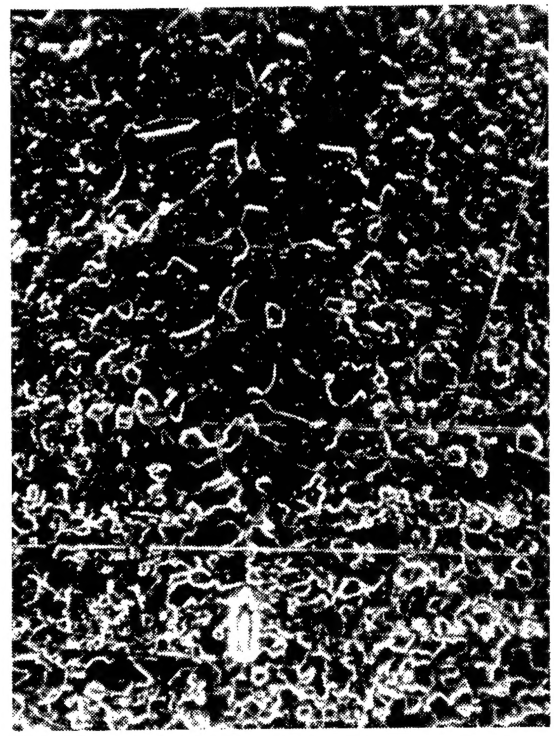

Figure 4. *Dark field photomicrograph showing weld area and depth: width ratio (3:1) at the weld (52X).*

The yield, ultimate tensile strength, and elongation were determined on the parent material for comparison with the welded specimens. Tensile specimens for these studies were cut from the 0.080-inch tantalum sheet to the dimensions shown in Figure 5. The thickness and width of the tensile specimen were measured and recorded to the nearest 0.001 inch. Five specimens were tested at a strain rate of 0.02 inch per inch per minute; the following results were obtained:

Average ultimate tensile strength	42,350 ± 500 psi
Average yield strength	30,000 ± 350 psi
Average elongation	40.5%

Mechanical Properties of the Weld Metal

Microhardness tests were conducted on the weld metal. The average Vickers' microhardness was 150 kg/mm^2 as compared to the microhardness of 105 kg/mm^2 for the parent metal.

Table 2

Impurity Analysis of Tantalum Sheet[a]

Impurity	(ppm)	Impurity	(ppm)
C	17	Sb	<25
O	56	Al	<25
N	15	Cu	<1
Fe	7	Ti	<5
Cr	<5	Mo	<10
Ni	<5	W	<40
Si	41		

[a]Certified heat analysis by National Research Corporation, Metals Division.

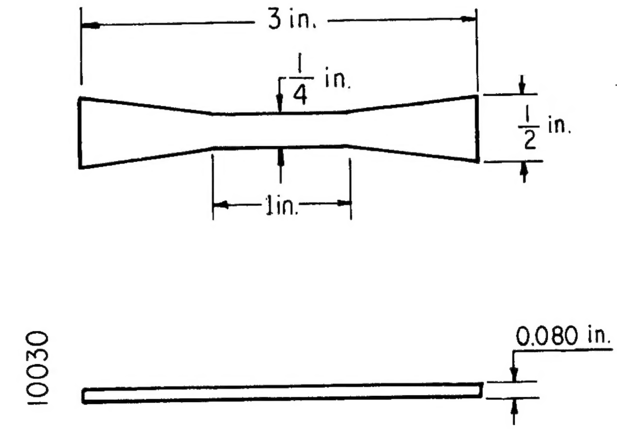

Figure 5. *Tensile specimen for the welding study.*

Mechanical properties of the weld metal were determined on six test specimens which were made by machining the weld overlay from the top surface, and the unwelded area from the bottom surface of the tensile specimens as shown in Figure 5. Although this method resulted in a specimen with a smaller cross section than the standard tensile specimen, the results were calculated using actual measured dimensions (average 0.065 inch thick x 0.250 inch wide) of the machined specimens. The results for samples using a one-inch gage length and a strain rate of 0.02 inch per inch per minute are presented below:

Average ultimate tensile strength	44,000 ± 2000 psi
Average yield strength	31,750 ± 1700 psi
Average elongation	23.5%

The slight increases in tensile and yield strength in comparison to the parent material were due to hardening of the weld area by recrystallization of the metal during welding. The average percentage elongation, however, dropped to about half that of the parent material for the same reason.

Welding of 0.010 x 0.010-inch Step Joints

A 0.010 x 0.010-inch step joint (Figures 6 and 7), 1.5 inches long, was chosen to optimize joint efficiency (ratio of ultimate tensile strength of the weld material to that of the parent material) and to insure less than 100% penetration of the sheet stock. A close fitting joint was necessary for precise control of the depth of penetration. After a number of sample welds were made, it was found that parameters of 120 kilovolts, 6.0 milliamperes, and 30 inches per minute welding speed gave the desired 0.070-inch penetration to the bottom of the step. A weld using these parameters is shown in Figure 6. Temperatures directly under the weld area (measured using a chromel-alumel thermocouple) reached a maximum of 300°C for a short time during the welding operation.

Tensile specimens of the weld area material were made with the same one-inch test area as the parent material (Figure 5). The one-inch gage length specimens were pulled at a strain rate 0.02 inch per inch per minute with the following results:

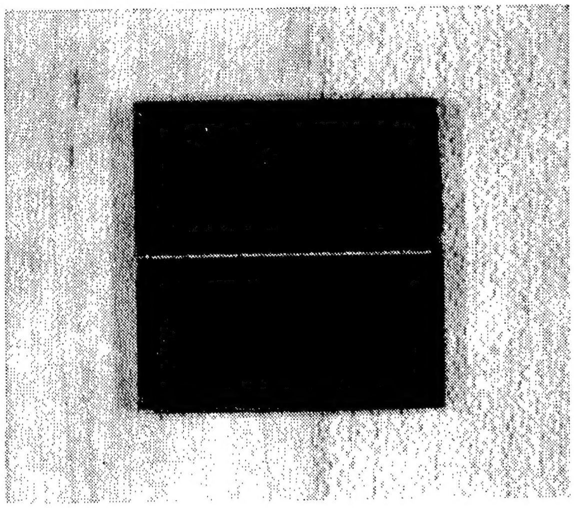

Figure 6. *This weld coupon, shown actual size, has a 0.010 x 0.010-inch step joint.*

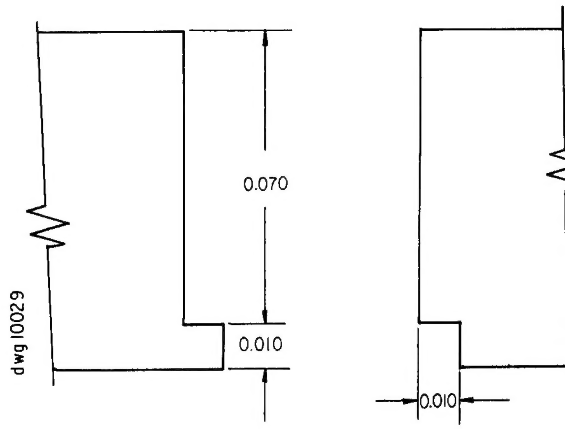

Figure 7. *Detail of 0.010 x 0.010-inch step joint.*

Average ultimate tensile strength	41,350 ± 900 psi
Average yield strength	30,050 ± 700 psi
Average elongation	18.5%

All tensile specimens broke at the root of the weld as shown in Figure 8. The localized neck-down in the photograph and recrystallization of the weld metal account for the large difference in elongation of the weld material (18.5%) as compared to the base metal (40.5%). The joint efficiency, however, was 97%, which was much greater than expected.

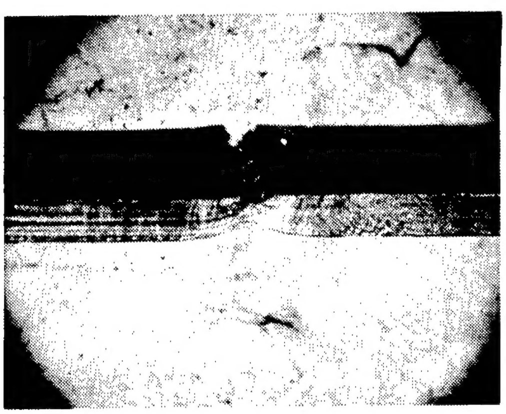

Figure 8. *Tensile specimen showing the weld break at the root of the step joint. Note the localized neck-down in the weld area.*

Since it was difficult to machine 0.010-inch step joints in the annealed tantalum sheet, 0.020 x 0.020-inch step joints were evaluated.

Welding of 0.020 x 0.020-inch Step Joints

Weld specimens were prepared with 0.020 x 0.020-inch step joints to obtain the optimum welding parameters that would yield weld penetration to the step—0.060 inch in this case. It was also necessary to determine whether the decrease in total weld depth (0.010 inch less) would seriously decrease the joint efficiency and ultimate tensile strength of the welds. An accelerating potential of 120 kilovolts, a beam current of 5.5 milliamperes, and a welding speed of 30 inches per minute were found to be the optimum parameters.

Tensile specimens were prepared using these welding parameters and the test specimen design shown in Figure 5. These tensile specimens broke, as did the previous specimens, at the weld root; however, the joint efficiency was 92%, compared to 97% for the 0.010-inch step. The following test results were obtained:

Average ultimate tensile strength	38,950 ± 1200 psi
Average yield strength	30,450 ± 600 psi
Average elongation	15.5%

Again, the percentage elongation was less than that of the base metal (15.5% compared to 40.5%) due to recrystallization of the weld metal and to the localized neck-down in the weld area during testing.

Conclusions

This study showed that electron beam welding can be used to join annealed tantalum sheet with joint efficiencies greater than 90%. This joint efficiency, possibly due to hardening of the weld metal during the welding process, was obtained with only 75% penetration of the total thickness of the tantalum sheet. Thus, the study indicated that 100% metal penetration is unnecessary for satisfactory joint efficiency.

Due to the low power requirements (1320 joules per inch of joint) the maximum temperature at the sheet surface opposite the weld was 300°C. Additionally, the temperature was at its maximum only momentarily at each point on the weld and rapidly decreased after the weld pass was made. The welding operation caused little or no distortion of the welded specimens.

Good joint fits were required to obtain reproducible weld penetration and to assure joints of predetermined strengths. Although it was not fully substantiated, joints with gaps no greater than 0.002 inch should be provided for best results.